

hammer. Otherwise, negative work is performed and the drill experiences a loss of performance (i.e., reduced impact energy) and an increase in Joule heating (i.e., reduction in energy efficiency). This observation has motivated many drilling products to incorporate the standard bang-bang control approach for driving their percussive drills. However, the bang-bang control approach is significantly less efficient than the optimal energy-efficient control approach solved herein.

To obtain this solution, the standard tools of classical optimal control theory were applied. It is worth noting that these tools inherently require the solution of a two-point boundary value problem

(TPBVP), i.e., a system of differential equations where half the equations have unknown boundary conditions. Typically, the TPBVP is impossible to solve analytically for high-dimensional dynamic systems. However, for the case of the spring-loaded vibro-impactor, this approach yields the exact optimal control solution as the sum of four analytic functions whose coefficients are determined using a simple, easy-to-implement algorithm. Once the optimal control waveform is determined, it can be used optimally in the context of both open-loop and closed-loop control modes (using standard real-time control hardware).

Future NASA *in situ* exploration missions increasingly require extensive

drilling and coring procedures that stress the demand for more energy efficient methods to accomplish these tasks. For example, when rover-based autonomous drills are controlled non-optimally for long periods of time, the energy loss can grow at a rate that cannot be sustained by the rover's internal energy supply. Motorized percussive units can be especially energy-draining (when controlled non-optimally), making this technology especially relevant to this type of future NASA work.

This work was done by Jack B. Aldrich and Avi B. Okon of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48467

Low-Cost Telemetry System for Small/Micro Satellites

Marshall Space Flight Center, Alabama

A Software Defined Radio (SDR) concept uses a minimum amount of analog/radio frequency components to up/downconvert the RF signal to/from a digital format. Once in the digital domain, all other processing (filtering, modulation, demodulation, etc.) is done in software. The project will leverage existing designs and enhance capabilities in the commercial sector to provide a path to a radiation-hardened SDR transponder.

The SDR transponder would incorporate baseline technologies dealing with improved Forward Error Correcting (FEC) codes to be deployed to all Near Earth Network (NEN) ground stations.

By incorporating this FEC, at least a ten-fold increase in data throughput can be achieved.

A family of transponder products can be implemented using common platform architecture, allowing new products to be more quickly introduced into the market. Software can be reused across products, reducing software/hardware costs dramatically. New features and capabilities, such as encoding and decoding algorithms, filters, and bit synchronizers, can be added to the existing infrastructure without requiring major new capital expenditures, allowing implementation of advanced features in the communication systems.

As new telecommunication technologies emerge, incorporating them into the SDR fabric will be easily accomplished with little or no requirements for new hardware. There are no preferred flight platforms for the SDR technology, so it can be used on any type of orbital or sub-orbital platform, all within a fully radiation hardened design.

This work was done by William Sims and Kosta Varnavas of Marshall Space Flight Center.

This invention is owned by NASA, and a patent application has been filed. For further information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. Refer to MFS-32871-1.

Operator Interface and Control Software for the Reconfigurable Surface System Tri-ATHLETE

The capability of future exploration missions may be greatly extended for a small additional cost.

NASA's Jet Propulsion Laboratory, Pasadena, California

Graphical operator interface methods have been developed for modular, reconfigurable articulated surface systems in general, and a specific instantiation thereof for JPL's Tri-ATHLETE. The All-Terrain Hex-Limbed Extra-Terrestrial Explorer Robot (ATHLETE) has six limbs with six kinematic degrees of freedom each (see figure).

The core advancement of this work was the development of a novel set of algorithms for dynamically maintaining a reduced coordinate model of any connected assembly of robot modules. The kinematics of individual modules are first modeled using a catalog of 12 standard 3D robot joints (this modeling step needs to be done only once). Then, in-

dividual modules can be assembled into any closed- or open-chain topology. The system automatically maintains a spanning tree of the overall configuration, which ensures both efficiency and accuracy of the on-screen representation.

Until now, JPL has used generic CAD (computer-aided design), simulation, and animation tools as a substitute for a